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(54) **FAN STAGGER ANGLE FOR DIRT REJECTION**

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(51) **Int. Cl.**

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F01D 25/34	(2006.01)
F02C 7/05	(2006.01)
F02K 3/06	(2006.01)

(52) **U.S. Cl.**

CPC . ***F02C 7/36*** (2013.01); ***F01D 15/12*** (2013.01); ***F01D 25/34*** (2013.01); ***F02C 7/05*** (2013.01); ***F02K 3/06*** (2013.01)

(58) **Field of Classification Search**

CPC F02C 7/36; F02C 7/05; F01D 15/12; F01D 25/34; F02K 3/06

USPC .... 415/121.2; 416/223 A, 239

See application file for complete search history.

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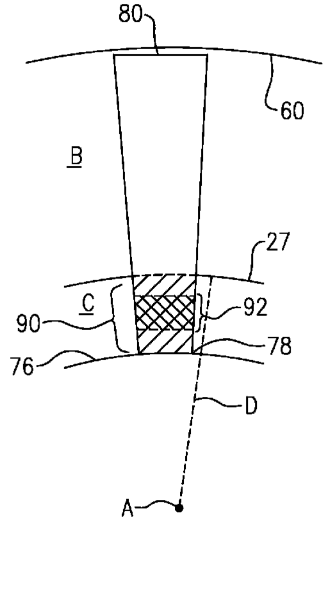
(57) **ABSTRACT**

A gas turbine engine includes a spool, a turbine coupled to drive the spool, a propulsor coupled to be rotated about an axis by the turbine through the spool, and a gear assembly coupled between the propulsor and the spool such that rotation of the turbine drives the propulsor at a different speed than the spool. The propulsor includes a hub and a row of propulsor blades that extend from the hub. Each of the propulsor blades has a span between a root at the hub and a tip, and a chord between a leading edge and a trailing edge. The chord forms a stagger angle α with the axis, and the stagger angle α is less than 15° at a position along the propulsor blade that is within an inboard 20% of the span.

23 Claims, 3 Drawing Sheets



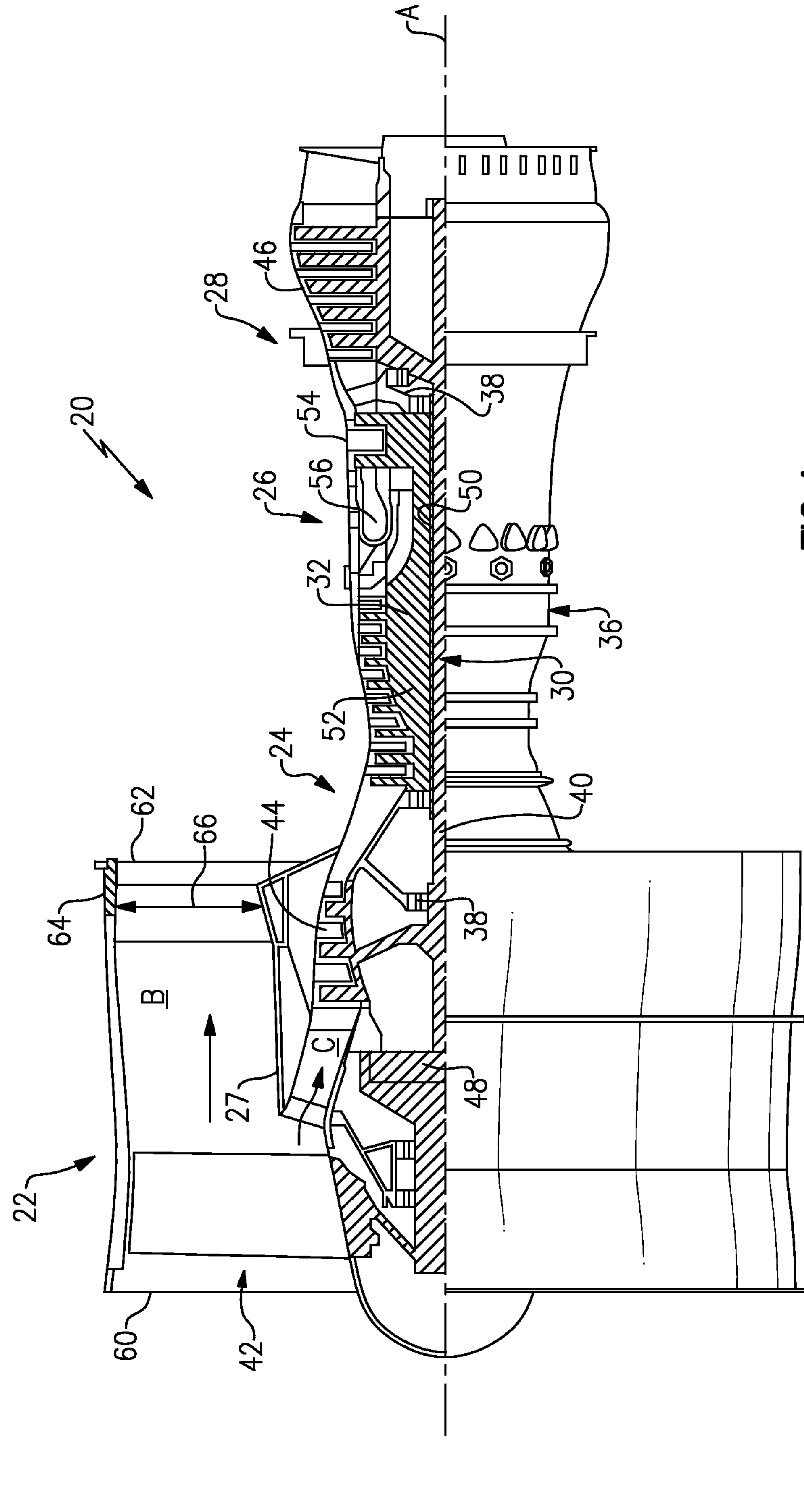

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FIG.1

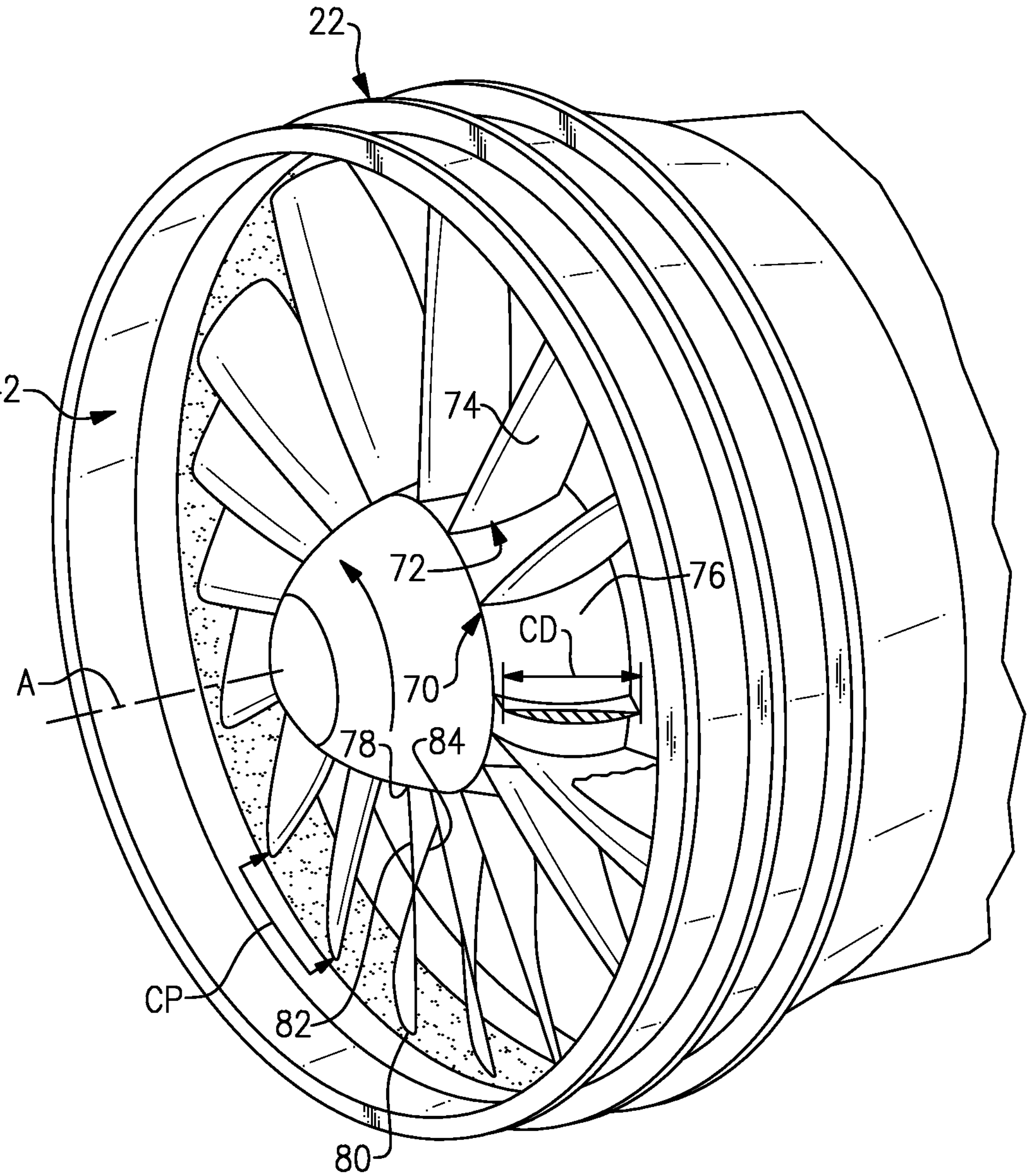

FIG.2

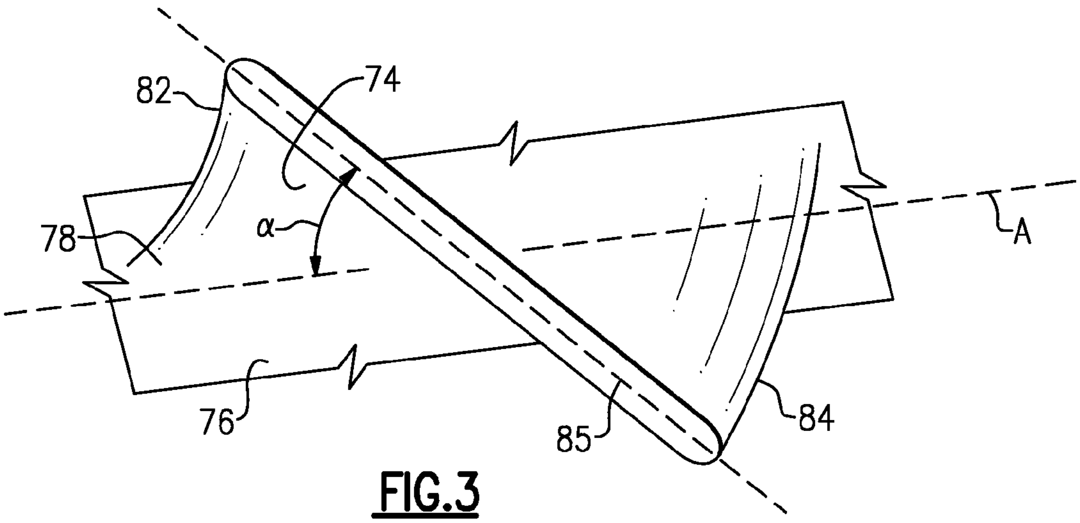

FIG.3

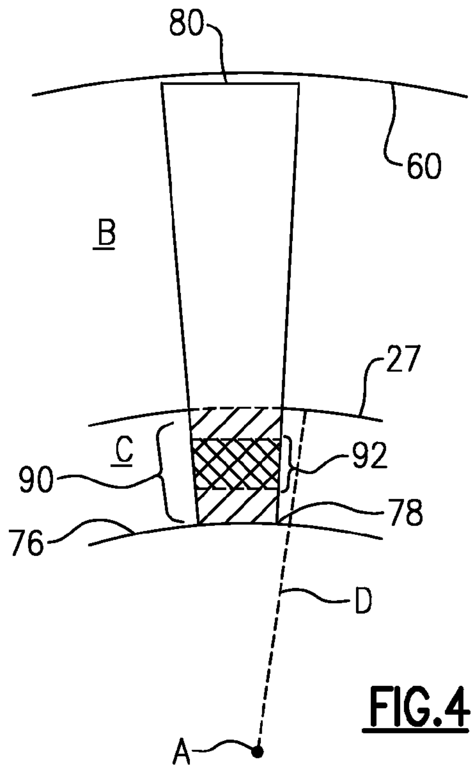

FIG.4

FAN STAGGER ANGLE FOR DIRT REJECTION

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made with government support under contract number NAS3-01138 awarded by NASA. The government has certain rights in the invention.

BACKGROUND

This disclosure relates to gas turbine engines and, more particularly, to an engine having a geared turbofan architecture that is designed to operate with a high bypass ratio and a low pressure ratio.

A gas turbine engine of an aircraft often ingests foreign objects, such as particulate matter. The particulate matter may be dirt, sand or the like. If the particulate matter is permitted to pass into the core flow of the engine, it may damage the engine compressor or other downstream engine components.

SUMMARY

Disclosed is a gas turbine engine and propulsor. The gas turbine engine includes a spool, a turbine coupled to drive the spool, the propulsor coupled to be rotated about an axis by the turbine through the spool, and a gear assembly coupled between the propulsor and the spool such that rotation of the turbine drives the propulsor at a different speed than the spool.

The propulsor includes a hub and a row of propulsor blades that extend from the hub. Each of the propulsor blades has a span between a root at the hub and a tip, and a chord between a leading edge and a trailing edge. The chord forms a stagger angle α with the axis, and the stagger angle α is less than 15° at a position along the propulsor blade that is within an inboard 20% of the span. An objective of the disclosed stagger angle α, in combination with the geared architecture of the engine, is the avoidance of ingestion of particulate matter into the core flow of the engine.

In another aspect, an example gas turbine engine includes a compressor section that extends along a central axis and includes an annular splitter that is spaced a radial distance (D) from the central axis such that there is a core flow radially inward of the annular splitter and a bypass flow radially outward of the annular splitter. A propulsor is located near the compressor section and includes a hub and a row of propulsor blades that extends from the hub. Each of the propulsor blades has a span between a root at the hub and a tip, and a chord between a leading edge and a trailing edge such that the chord forms a stagger angle α with the central axis. The stagger angle α is less than 15° at a position along the propulsor blade that is radially inward of the radial distance (D).

BRIEF DESCRIPTION OF THE DRAWINGS

The various features and advantages of the disclosed examples will become apparent to those skilled in the art from the following detailed description. The drawings that accompany the detailed description can be briefly described as follows.

FIG. **1** is a schematic cross-section of a gas turbine engine.

FIG. **2** is a perspective view of a fan section of the engine of FIG. **1**.

FIG. **3** is an isolated view of a propulsor blade and portion of a hub.

FIG. **4** is an axial view of a propulsor blade and portion of a hub.

DETAILED DESCRIPTION

In a turbofan engine, the fan (e.g., propulsor) is a first line of protection from the ingestion of particulate matter into the core flow of the engine. The fan is designed with blade stagger to induce air swirl that helps move incoming particulate matter into the bypass rather than allow the particulate to enter into the core flow. The blade stagger is typically apparent when viewing the fan axially from the front of the engine. In a turbofan engine architecture where the turbine of the engine directly drives the fan at the same angular speed as the turbine, the stagger angle is severe such that an observer would not be able to see past the fan into the engine because the fan blades are angled with the broad sides turned to the observer.

The stagger angle may be a function, at least in part, of a variety of factors, such as the number of blades on the fan, the design pressure ratio of the engine, the design bypass ratio of the engine, the solidity of the fan blades and the rotational speed of the fan blades at full throttle as a function of position along the span of the blades.

As will be described, a disclosed gas turbine engine **20** incorporates a geared architecture and a propulsor **42** that is designed with consideration to at least some of the above factors to achieve a high level of particulate rejection for the geared architecture arrangement and designed operation.

FIG. **1** schematically illustrates the gas turbine engine **20**. The gas turbine engine **20** may be a two-spool turbofan that generally incorporates a fan section **22**, a compressor section **24**, a combustor section **26** and a turbine section **28**. Although depicted as a turbofan gas turbine engine, it is to be understood that the concepts described herein are not limited to use with the disclosed arrangement. Alternative engine architectures may include a single-spool design, a three-spool design, or an open rotor design, among other systems or features.

The fan section **22** drives air along a bypass flow passage B while the compressor section **24** drives air along a core flow passage C for compression and communication into the combustor section **26**. An annular splitter **27**, located adjacent the fan section **22**, generally surrounds the compressor section **24** and establishes the core flow passage C.

The engine **20** includes a low speed spool **30** and high speed spool **32** mounted for rotation about an engine central longitudinal axis A relative to an engine static structure **36** via several bearing systems **38**. The fan section **22** and the compressor section **24** are concentric with the engine central longitudinal axis A. The low speed spool **30** generally includes an inner shaft **40** that is coupled with the propulsor **42**, a low pressure compressor **44** and a low pressure turbine **46**. The low pressure turbine **46** drives the propulsor **42** through the inner shaft **40** and a gear assembly **48**, which allows the low speed spool **30** to drive the propulsor **42** at a different (e.g. lower) angular speed.

The high speed spool **32** includes an outer shaft **50** that is coupled with a high pressure compressor **52** and a high pressure turbine **54**. A combustor **56** is arranged between the high pressure compressor **52** and the high pressure turbine **54**. The inner shaft **40** and the outer shaft **50** are concentric and rotate about the engine central longitudinal axis A, which is colinear with their longitudinal axes.

A core airflow in the core flow passage C is compressed in the low pressure compressor **44** then the high pressure compressor **52**, mixed with the fuel and burned in the combustor **56**, and then expanded over the high pressure turbine **54** and low pressure turbine **46**. The turbines **54**, **46** rotationally drive the respective low speed spool **30** and high speed spool **32** in response to the expansion.

As shown, the propulsor **42** is arranged at an inlet **60** of the bypass flow passage B and the core flow passage C. Air flow through the bypass flow passage B exits the engine **20** through an outlet **62** or nozzle. For a given design of the propulsor **42**, the inlet **60** and the outlet **62** establish a design pressure ratio with regard to an inlet pressure at the inlet **60** and an outlet pressure at the outlet **62** of the bypass flow passage B. As an example, the design pressure ratio may be determined based upon the stagnation inlet pressure and the stagnation outlet pressure at a design rotational speed of the engine **20**. In that regard, the engine **20** may optionally include a variable area nozzle **64** within the bypass flow passage B. The variable area nozzle **64** is operative to change a cross-sectional area **66** of the outlet **62** to thereby control the pressure ratio via changing pressure within the bypass flow passage B. The design pressure ratio may be defined with the variable area nozzle **64** fully open or fully closed.

Referring to FIG. **2**, the propulsor **42**, which in this example is a fan, includes a rotor **70** having a row **72** of propulsor blades **74** that extend circumferentially around a hub **76**. Each of the propulsor blades **74** extends radially outwardly from the hub **76** between a root **78** and a tip **80**, and in a chord direction (axially and circumferentially) between a leading edge **82** and a trailing edge **84**. A chord **85** (see FIG. **3**), also represented by chord dimension (CD), is a straight line that extends between the leading edge **82** and the trailing edge **84** of the propulsor blade **74**. The chord dimension (CD) may vary along the span of the propulsor blade **74**. For the purpose of later defining solidity, the chord dimension (CD) may be taken at the tips **80** of the propulsor blades **74**. The row **72** of propulsor blades **74** also defines a circumferential pitch (CP) that is equivalent to the arc distance between the tips **80** of neighboring propulsor blades **74**.

FIG. **3** shows an isolated view of one of the propulsor blades **74** and portion of the hub **76**. As shown, the propulsor blade **74** is sectioned at a radial position between the root **78** and the tip **80**. The radial position along the propulsor blade **74** can be represented as a percentage of the span of the propulsor blade **74**, with the root **78** representing a 0% span and the tip **80** representing a 100% span. The chord **85** is shown on the section of the propulsor blade **74**. The chord **85** forms an angle, stagger angle α, with the engine central longitudinal axis A. The stagger angle α can vary with position along the span. The angle can alternatively be represented as an angle between the chord **85** and a line that is orthogonal to the engine central longitudinal axis A, which is equal to 90°−α.

The stagger angle α of the propulsor blades **74** is designed to facilitate the rejection of particulate matter into the bypass flow passage B for a geared architecture. The gear assembly **48** of the disclosed example permits the propulsor **42** to be driven by the low pressure turbine **46** through the low speed spool **30** at a lower angular speed than the low pressure turbine **46**. In embodiments, the stagger angle α of the propulsor blades **74** is designed for effective particulate matter rejection at that lower speed operation.

FIG. **4** shows an axial view of one of the propulsor blades **74** and portion of the hub **76**. The stagger angle α within a section of the span of the propulsor blades **74** is designed for the given geared architecture and lower angular speed at full throttle. In embodiments, the stagger angle α is less than 15° at a position along the propulsor blades **74** that is within an inboard 20% of the span, represented at **90**, with the hub **76** being at 0% of the span and the tip **80** being at 100% of the span. In a further embodiment, the stagger angle α is less than 15° at a position along the propulsor blades **74** that is within the range of 5%-15% span, as represented at **92**. The spatial orientation of the propulsor blades **74** that results from the disclosed stagger angle α increases the probability that incoming **25** particulate matter will strike the propulsor blades **74** and be rejected into the bypass flow passage B rather than the core flow passage C.

In a further embodiment, the stagger angle α is less than 10° within the inboard 20% of the span or the range of 5%-15% span. Alternatively, the stagger angle α is less than 5° within the inboard 20% of the span or the range of 5%-15% span. In some embodiments, the chord **85** may be substantially parallel to the engine longitudinal central axis A (e.g., within +/−2°) such that the stagger angle α is approximately 0° within the inboard 20% of the span or the range of 5%-15% span.

The stagger angle α may also be described with regard to the location of the annular splitter **27**. The annular splitter **27** is spaced a radial distance (D) from the engine longitudinal central axis. The disclosed stagger angles α may be at a position along the propulsor blade **74** that is radially inward of the radial distance (D).

In general, the selected stagger angle α may follow an inverse relationship to the design bypass ratio of the engine **20** with regard to the amount of air that passes through the bypass flow passage B and the amount of air that passes through the core flow passage C such that lower stagger angles correspond to higher bypass ratio designs, and vice versa. In embodiments, the stagger angle α may be less than 15° for a design bypass ratio of 12 and the stagger angle α may be less than 5° for a design bypass ratio of 18.

As described, the stagger angle α may also be a function, at least in part, of the number of blades, the design pressure ratio, the design bypass ratio, and the solidity of the blades. In that regard, embodiments of the propulsor blades **74** may also have some or all of the below-described properties in combination with the disclosed stagger angles α.

In embodiments, the propulsor **42** may include a number (N) of the propulsor blades **74** in the row **72** that is no more than 20. For instance, the number N may be any number from 10 to 20.

Additionally, the propulsor blades **74** define a solidity value with regard to the chord dimension CD at the tips **80** and the circumferential pitch CP. The solidity value is defined as a ratio (R) of CD/CP (i.e., CD divided by CP). In embodiments, the solidity value of the propulsor **42** is between 0.6 and 1.3.

The engine **20** may also be designed with a particular design pressure ratio. In embodiments, the design pressure ratio may be between 1.1 and 1.55.

The engine **20** may also be designed with a particular bypass ratio with regard to the amount of air that passes through the bypass flow passage B and the amount of air that passes through the core flow passage C. As an example, the design bypass ratio of the engine **20** may nominally be 12 or greater.

The propulsor **42** also defines a ratio of N/R. In embodiments, the ratio N/R is between 8 and 28. Tables 1 and 2 below show additional examples of solidity and the ratio N/R for different numbers of propulsor blades **74** that can be used with the disclosed stagger angles α.

TABLE 1

Number of Blades, Solidity and Ratio N/R		
Number of Blades (N)	Solidity	Ratio N/R
20	1.3	15.4
18	1.3	13.8
16	1.3	12.3
14	1.3	10.8
12	1.3	9.2
20	1.2	16.7
18	1.2	15.0
16	1.2	13.3
14	1.2	11.7
12	1.2	10.0
20	1.1	18.2
18	1.1	16.4
16	1.1	14.5
14	1.1	12.7
12	1.1	10.9
20	1.0	20.0
18	1.0	18.0
16	1.0	16.0
14	1.0	14.0
12	1.0	12.0

TABLE 2

Number of Blades, Solidity and Ratio N/R		
Number of Blades (N)	Solidity	Ratio N/R
16	1.1	14.5
14	1.1	12.7
12	1.1	10.9
10	1.1	9.1
16	1.02	15.7
14	1.02	13.7
12	1.02	11.8
10	1.02	9.8
16	0.89	18.0
14	0.89	15.7
12	0.89	13.5
10	0.89	11.2
16	0.76	21.1
14	0.76	18.4
12	0.76	15.8
10	0.76	13.2
16	0.63	25.4
14	0.63	22.2
12	0.63	19.0
10	0.63	15.9
16	0.60	26.7
14	0.60	23.3
12	0.60	20.0
10	0.60	16.7

The disclosed ratios of N/R also enhance the propulsive efficiency of the disclosed engine **20**. For instance, the disclosed ratios of N/R are designed for the geared turbofan architecture of the engine **20** that utilizes the gear assembly **48**. That is, the gear assembly **48** allows the propulsor **42** to rotate at a different, lower speed than the low speed spool **30**. In combination with the variable area nozzle **64**, the propulsor **42** can be designed with a large diameter and rotate at a relatively slow speed with regard to the low speed spool **30**. A relatively low speed, relatively large diameter, and the geometry that permits the disclosed ratios of N/R contribute to the reduction of performance debits, such as by lowering the speed of the air or fluid that passes over the propulsor blades **74**.

Although a combination of features is shown in the illustrated examples, not all of them need to be combined to realize the benefits of various embodiments of this disclosure. In other words, a system designed according to an embodiment of this disclosure will not necessarily include all of the features shown in any one of the Figures or all of the portions schematically shown in the Figures. Moreover, selected features of one example embodiment may be combined with selected features of other example embodiments.

The preceding description is exemplary rather than limiting in nature. Variations and modifications to the disclosed examples may become apparent to those skilled in the art that do not necessarily depart from the essence of this disclosure. The scope of legal protection given to this disclosure can only be determined by studying the following claims.

What is claimed is:

1. A gas turbine engine comprising:
a spool;
a turbine coupled with said spool;
a propulsor coupled to be rotated about an axis by said turbine through said spool; and
a gear assembly coupled between said propulsor and said spool such that rotation of said turbine drives said propulsor at a different speed than said spool,
wherein said propulsor includes a hub and a row of propulsor blades that extend from said hub, each of said propulsor blades has a span between a root at said hub and a tip, and a chord between a leading edge and a trailing edge such that said chord forms a stagger angle α with said axis, and said stagger angle α is less than 15° at a position along said propulsor blade that is within an inboard 20% of said span, with said hub being at 0% of said span and said tip being at 100% of said span.

2. The gas turbine engine as recited in claim **1**, wherein said stagger angle α is less than 10° at said position.

3. The gas turbine engine as recited in claim **1**, wherein said stagger angle α is less than 5° at said position.

4. The gas turbine engine as recited in claim **1**, wherein said chord at said position is substantially parallel to said axis.

5. The gas turbine engine as recited in claim **1**, wherein said position is within 5-15% of said span.

6. The gas turbine engine as recited in claim **1**, wherein said propulsor is located at an inlet of a bypass flow passage having a design pressure ratio that is between 1.1 and 1.55 with regard to an inlet pressure and an outlet pressure of said bypass flow passage.

7. The gas turbine engine as recited in claim **1**, wherein said chord has a chord dimension (CD) at said tips, said row of propulsor blades defines a circumferential pitch (CP) with regard to said tips, and said row of propulsor blades has a solidity value (R) defined as CD/CP that is between 0.6 and 1.3.

8. The gas turbine engine as recited in claim **1**, wherein said row of propulsor blades includes a number (N) of said propulsor blades that is no more than 20.

9. The gas turbine engine as recited in claim **1**, wherein said chord has a chord dimension (CD) at said tips, said row of propulsor blades defines a circumferential pitch (CP) with regard to said tips, said row of propulsor blades has a solidity value (R) defined as CD/CP, and said row of propulsor blades includes a number (N) of said propulsor blades that is no more than 20 such that a ratio of N/R is between 8 and 28.

10. The gas turbine engine as recited in claim **1**, wherein said stagger angle α varies with position of said chord along said span.

11. The gas turbine engine as recited in claim **1**, wherein said stagger angle α is less than 5° at said position to reject particulate into a bypass flow passage.

12. The gas turbine engine as recited in claim **11**, wherein said bypass flow passage has a bypass ratio of 18.

13. A gas turbine engine comprising:

a compressor section that extends along a central axis and includes an annular splitter spaced a radial distance (D) from said central axis such that there is a core flow radially inward of said annular splitter and a bypass flow radially outward of said annular splitter; and

a propulsor adjacent said compressor section, said propulsor including a hub and a row of propulsor blades that extend from said hub, each of said propulsor blades has a span between a root at said hub and a tip, and a chord between a leading edge and a trailing edge such that said chord forms a stagger angle α with said central axis, and said stagger angle α is less than 15° at a position along said propulsor blade that is radially inward of said radial distance (D).

14. The gas turbine engine as recited in claim **13**, wherein said position along said propulsor blade is within an inboard 20% of said span, with said hub being at 0% of said span and said tip being at 100% of said span.

15. The gas turbine engine as recited in claim **14**, wherein said position is within 5-15% of said span.

16. The gas turbine engine as recited in claim **13**, including a design bypass ratio with regard to said bypass flow and said core flow that is at least 12.

17. The gas turbine engine as recited in claim **13**, wherein said stagger angle α is less than 5° at said position to reject particulate into a bypass flow passage.

18. A propulsor for use in a gas turbine engine, the propulsor comprising:

a rotor including a row of propulsor blades extending radially outwardly from a hub that is rotatable around an axis, each of said propulsor blades has a span between a root at said hub and a tip, and a chord between a leading edge and a trailing edge such that said chord forms a stagger angle α with said axis, and said stagger angle α is less than 15° at a position along said propulsor blade that is within an inboard 20% of said span, with said hub being at 0% of said span and said tip being at 100% of said span.

19. The propulsor as recited in claim **18**, wherein said stagger angle α is less than 10° at said position.

20. The propulsor as recited in claim **18**, wherein said stagger angle α is less than 5° at said position.

21. The propulsor as recited in claim **18**, wherein said chord at said position is substantially parallel to said axis.

22. The propulsor as recited in claim **18**, wherein said position is within 5-15% of said span.

23. The propulsor as recited in claim **18**, wherein said stagger angle α is less than 5° at said position to reject particulate.

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